On the Complex Wilson Coefficients of New Physics Scenarios

L. Solmaz*
Balikesir University, Physics Department.(10100), Balikesir/Turkey

S. Solmaz†
Middle East Technical University, Physics Department. (06531),Ankara/Turkey

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Abstract

We draw attention on the procedure, where Standard Model predictions and experimental results are compared and certain new physics scenarios are ruled out, that requires great attention, since there is still a room for new physics, especially when contributions of extended models bear complex phases. We observe that this is true even when SM and experiment yield the same results with zero uncertainties.

I. INTRODUCTION AND CONCLUSION

At present for certain decays there are a number of impressive theoretical predictions in great agreement with the experimental results. Due to the consistency, uncertainties around one σ level seems acceptable. In general, the difference between Standard Model (SM) results and experimental values are seen on the half of New Physics (NP) scenarios and used to put constraints on the new parameters(i.e. see Ref.[1]). If SM predictions and experimental measurements are very close then naturally NP is orphaned. The aim of the present work is to draw attention on the side effects of bounding Wilson coefficients with the mentioned procedure.

One of the best examples of such decays is the $B \to X_s\gamma$ decay, which has solid theoretical and experimental background, widely used to test and constrain a number of NP scenarios. Recent review of this decay can be found in Ref.[2]. Taking into consideration NP effects, the present status of the decay related with branching ratio can be expressed as

$$\eta \pm \sigma = \alpha\, |C|^2\,, \tag{1}$$

where η, σ denotes experimental measurements and uncertainties, α satisfies proportionality related with the decay. With the definition, $C = C^{SM}(\mu) + C^{NP}(\mu)$, $C^{SM,NP}(\mu)$ are the Wilson coefficients at the low energy scale μ.

From the experimental side, average of experimental measurements of the branching ratio for the mentioned decay can be written as $Br(B \to X_s\gamma) = (\eta \pm \sigma) \times 10^{-4}$ with $\eta = 3.34$, $\sigma = 0.38$ Refs.[3, 4, 5, 6, 7, 8]. From the viewpoint of the SM the situation is very similar, roughly $\eta \sim 3.3 - 3.7$,6 $\sigma \sim 0.3$ Refs.[9, 10, 11, 12, 13].

It can be dreamed that one day theoretical and experimental results are very reliable and uncertainties are under control, even $\sigma_{Theory,Experiment} \to 0$ is approached. Meanwhile, σ is commented as a nice room for a number of new physics scenarios. Since, it can be used by NP, to fill the gap between SM theory and experiment. In the case when σ is converging to zero and SM predictions are right in the correct place, $C^{NP} \to 0$ and hence speculative existence of new physics is ruled out.

However, what should be stressed is that, this criteria is not enough to reject the possibility of a hidden NP. To make it clear assume the worst situation for NP, C^{SM} satisfies the equality given in Eq.1 without any theoretical or experimental error, whence no room for NP scenarios,

$$\frac{\eta \pm 0}{\alpha} = |C^{SM}(\mu)|^2 = |C^{SM}(\mu) + C^{NP}(\mu)|^2\,. \tag{2}$$

Notice that if $C^{NP}(\mu)$ is a real quantity, then 0 is the first solution for NP Wilson coefficient, second solution is $-2C^{SM}(\mu)$. Once it is assumed complex in the form

$$C^{NP}(\mu) = C_r(\mu) + iC_i(\mu)\,, \tag{3}$$

at first sight $C_r(\mu) = -C^{SM}(\mu), C_i(\mu) = \pm C^{SM}(\mu)$ is the solution, and the general solution for the NP scenario can be written as

$$C_r^2(\mu) + C_i^2(\mu) = -2C_r(\mu)C^{SM}(\mu)\,, \tag{4}$$

lying on the complex $C^{NP}(\mu)$ plane. Complex phases in the final form of Wilson coefficients is possible in certain extensions of the SM. As an example let us mention one of the most popular extensions of the SM, Two Higgs Doublet Model 2HDM(III) Ref.[14, 15, 16, 17]. In this model, not only at the matching scale μ_W but also for the μ_b scale there are complex couplings which can be written in the appropriate form as follows

$$C_7^{eff}(\mu) = C_7^{SM}(\mu) + C_{7,r}^{2HDM}(\mu) + iC_{7,i}^{2HDM}(\mu)\,. \tag{5}$$

Now, to see the effect of this approach, for simplicity, assume theoretical predictions of the SM and experimental results are given as follows

$$Br(B \to X_s\gamma)_{SM} \;=\; (\eta_{SM} \pm 0) \times 10^{-4}\,,$$

*Electronic address: lsolmaz@balikesir.edu.tr
†Electronic address: kerman@.metu.edu.tr

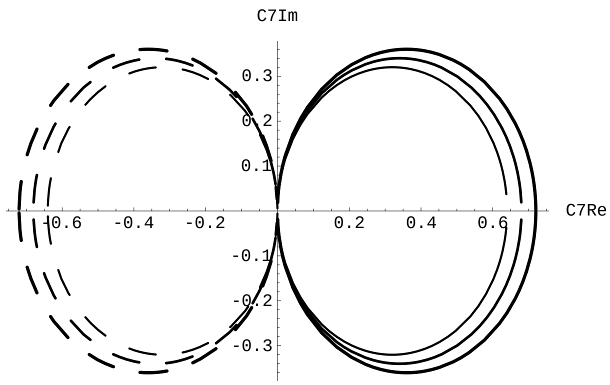

FIG. 1: Constraints on the new physics parameters $C_{7,r}^{NP}, C_{7,i}^{NP}$ with the assumption $\eta_{Exp,SM} = 3.5$, $\sigma_{Exp} = 0.4$. and $\alpha \simeq 30.4 \times 10^{-4}$. Dashed lines (solid lines) show negative (positive) choices of C_7^{SM}, with increasing order of thickness with the $\sigma = \{-0.4, 0, 0.4\}$ choices respectively.

$$Br(B \to X_s\gamma)_{Exp} \; = \; (\eta_{Exp} \pm \sigma_{Exp}) \times 10^{-4}\,; \qquad \eta_{Exp,SM} = 3.5,\; \sigma_{Exp} = 0.4\,. \tag{6}$$

In this approximation, Wilson coefficient of the SM takes $C_7^{SM} \sim \pm\{0.32, 0.34, 0.36\}$ values in accordance with the error σ_{Exp} is given in Eq.6. and the proportionality constant $\alpha \simeq 30.4 \times 10^{-4}$, is defined in Eq.1. Notice that we assume no uncertainty for σ_{SM} and set $\eta_{SM} = 3.5$, hence neglect theoretical errors on purpose. Considering new physics, allowed ranges of the new Wilson coefficients $C_{7,r}^{NP}$, $C_{7,i}^{NP}$ can be extracted from Fig.1. In the figure the choice $\sigma = 0$ is presented in the middle of both left and right regions, stressing the possible solutions of C_7^{NP} for $Br(B \to X_s\gamma)_{SM} = Br(B \to X_s\gamma)_{Experiment}$. By looking from one dimension if we set $C_{7,i}^{NP} = 0$, possible values of $C_{7,r}^{NP}$ can be extracted from the same figure 1. As it can be deduced from the figure, considering complex phases enriches phenomenology.

To summarize, scenarios permitting complex components in the final form of evolved Wilson coefficients have a rich potential for NP effects. Free parameters of NP should not be accepted as real from the beginning. Even if SM and experiment are in complete agreement, complex parts can help NP to survive, when we consider the issue as an alternative solution. While observing the possibility of such a structure of *New Physics*, branching ratio can not be used, solely, to refuse or accept a new model. Nevertheless, since we have well motivated theoretical and experimental background, it is possible to back-transform Eq.4. and obtain the most general form of the NP scenarios at the matching scale. The price we have to pay is, at least, two more unknowns which should be fixed by other measurements or probably best by CP asymmetry (A_{CP}) of the related decays.

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